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Army Ground Vehicles and Current/Future Emission Standards

Advanced Planning Briefing to Industry (APBI), October 23, 2008.

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Outline

- Opening Comment
- EPA Heavy-Duty Diesel Emission Standards
- Emission Control Technology Discussion
- Fuels and Lubricants Discussion
- Current Army Ground Vehicle Engine Philosophy and Conclusion

Opening Comment

- The Army can not buy 2007 or Tier IV (> 75 bhp) compliant COTS engines and directly integrate into current and new heavy-duty vehicles.

Regulatory Approach (2007)

EPA finalized motor vehicle diesel fuel regulations and the heavy duty diesel *on-road* exhaust emissions regulations in January 2001.

Took a dual approach to reduce air emissions by:

1. Reduction in diesel fuel sulfur concentration to 15ppm starting June 2006.
   - Enable the use of exhaust system aftertreatment devices
   - **JP-8 specification calls for < 3000 ppm!**
2. Establish stringent exhaust emission standards - effective **2007.**
   - Phased-in approach; fully meet standards in **2010**
   - Require aftertreatment device(s)
     - Particulate filters in 2007
     - NOx aftertreatment 2010 (traps or urea SCR)

(Both regulations implemented with a phased approach)

Off-road standards (Tier IV) similar in nature and 'lag' on-road standards by approximately three years depending on engine rated power

Potential Impacts to DoD

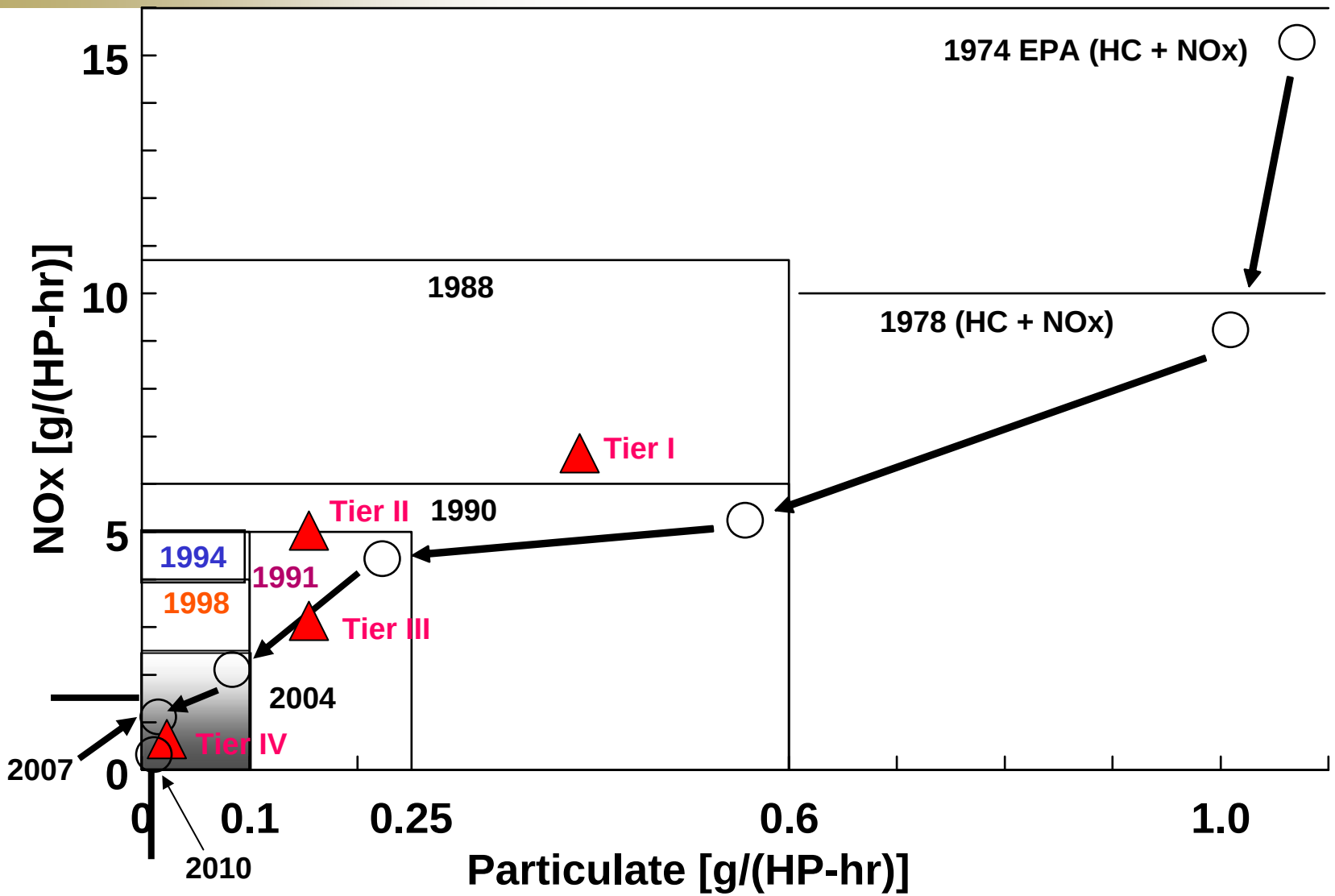
- **Ground tactical vehicles (i.e. HEMMT, PLS, HMMWV) operating in the U.S. required to meet the fuel 15 ppm sulfur regulation**
  - JP-8 does not meet this requirement (specification < 3000 ppm)
  - Global DF-2 does not meet this requirement
- **Procure vehicles with pollution control technology**
  - Potential performance degradation (fuel consumption, reliability, durability)
  - The current leading pollution control technology candidates are not readily compatible with military fluids and mobility requirements
  - Significant increase in vehicle thermal load
- **Nebulous world wide operation since low sulfur fuel is not available world wide:**
  - Low sulfur diesel fuel is an enabler for pollution control devices

(Combat vehicles (i.e. Abrams, Bradley, Stryker) are automatically exempt under 40 CFR, 89.908)

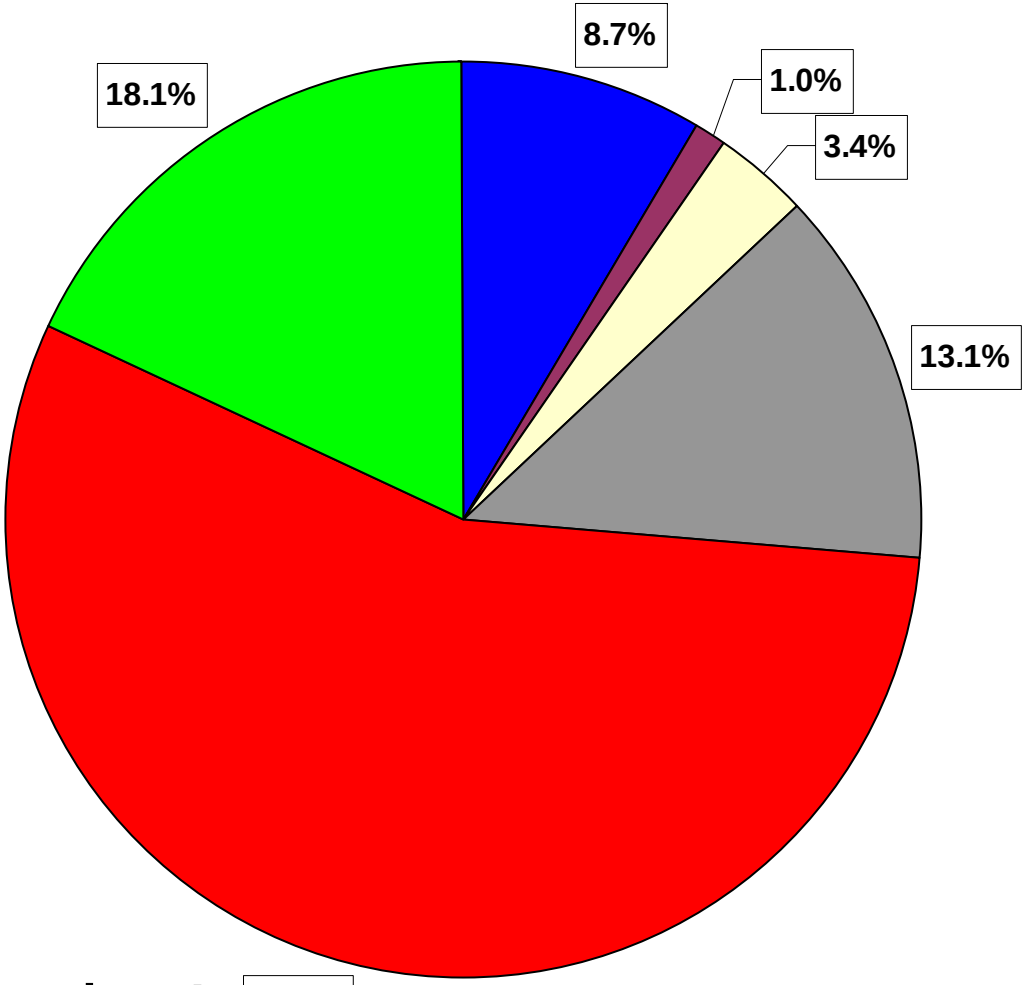
DoD Interaction with EPA

- **EPA approved NSE request for JP-8 exclusion from on-road 2006 and off-road 2007 diesel fuel regulations**
- **‘Blanket NSE’ granted from meeting 2007+ heavy-duty, on-road emission standards (August 23, 2005)**
- **‘Blanket NSE’ granted from 2004 on-road emission standards (November 15, 2006)**
- **Off-Road equipment Tier IV emission standards NSE granted by EPA (January 16, 2008)**

On-Road Versus Off-Road HD Standards (300 – 600 BHP)



Projected PEO CS&CSS FY08 to FY15 Engine Procurement Volumes



Over 100,000 engines!

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Army Ground Vehicle Propulsion Challenges

'Traditional Issues'

1. Cooling
2. Fuel Effects
3. Filtration

Evolving Need for Better Protection, i.e. More Weight

1. Cooling
2. Sluggish Mobility

The Army vehicle cooling point is high tractive effort to weight under desert-like operating conditions (ex. 5 ton wheeled vehicle ~0.6 while 15+ ton tracked vehicle ~0.7 both at 120 F ambient or higher)

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Emission Control Technology Discussion

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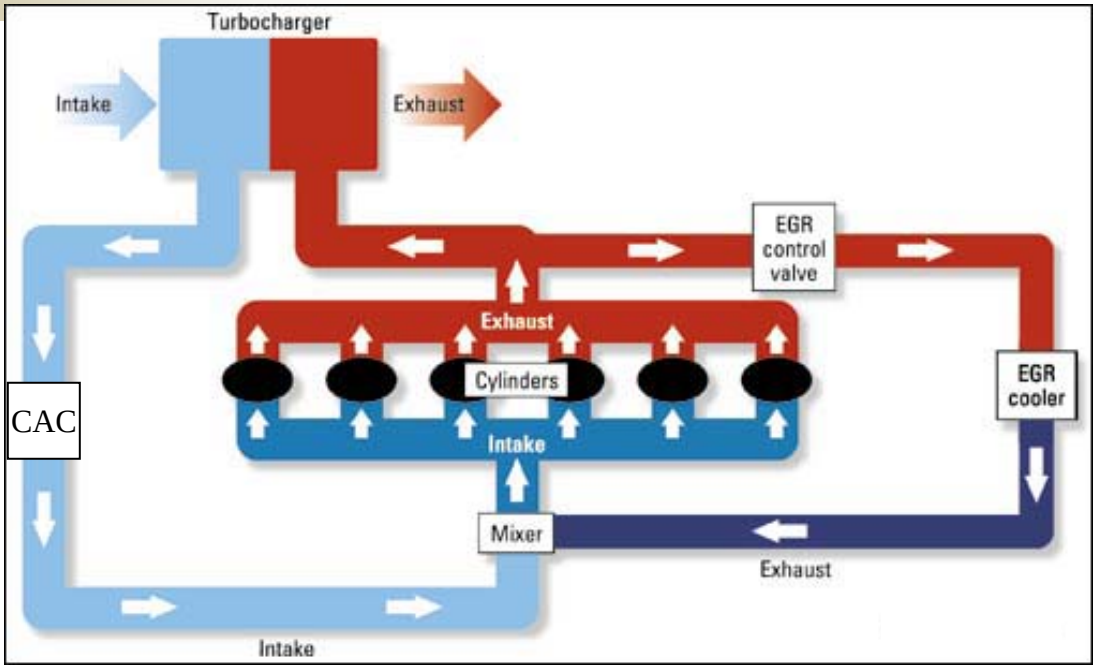
Impact of 2007 Emission Standards on Commercial Heavy-Duty Diesel Engines

- **C**ooled **E**xhaust **G**as **R**ecirculation (**EGR**) with advanced combustion and closed-loop engine system controls
- **Particulate Matter Filters**: catalyzed and non-catalyzed for incineration of trapped particulate matter
- **One particular precision air and fuel management strategy** plus closed-loop engine system controls along with low pressure ('filtered') EGR loop and PM filter
- *High Pressure Common Rail fuel systems that require a lubricity additive through a slow dosing fuel filter (OEMs need more flexible fuel systems for multiple event, high pressure fuel injection)*

- *2010 (projected): urea SCR and/or NOx trap, more EGR, more closed loop control;* ***new combustion regimes that may require specified fuel properties***

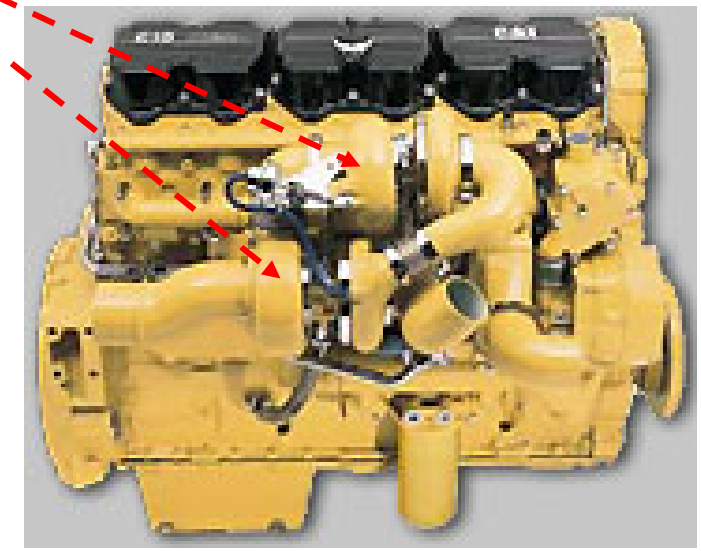
What is cooled EGR? (High Pressure)



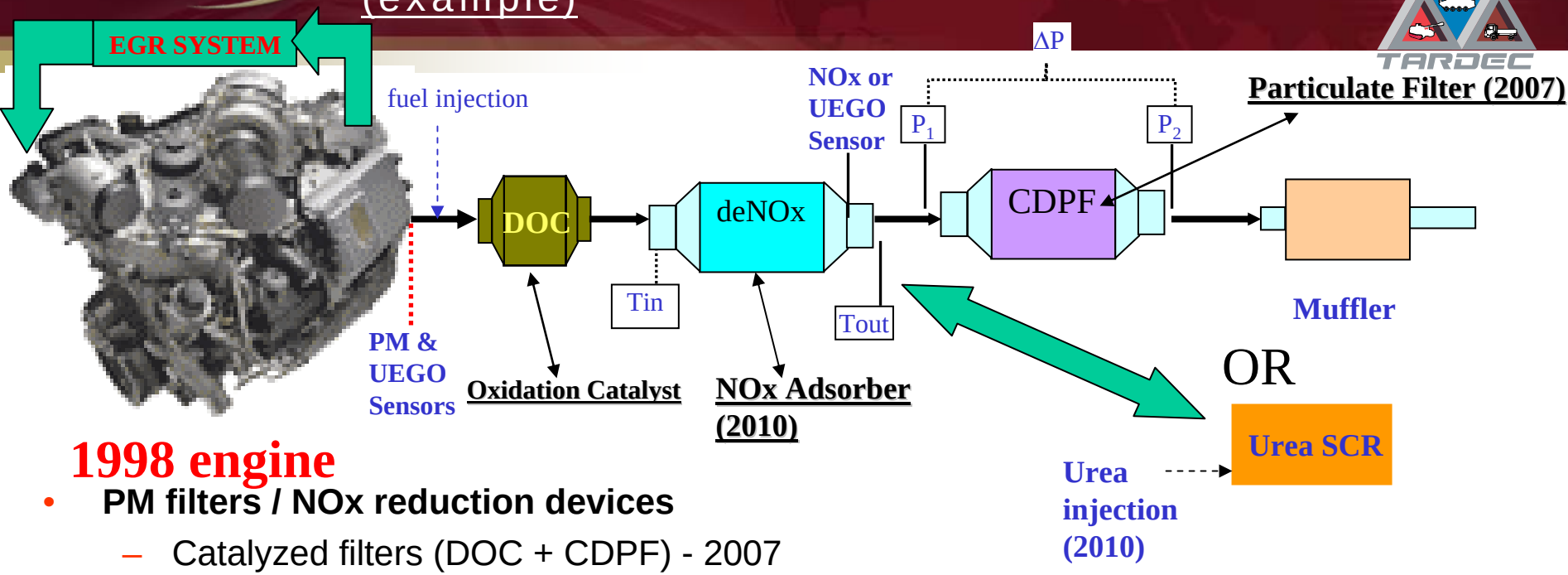
- Reduce nitrous oxides (NO_x) through 'cooler' combustion temperatures
- Recirculate and cool exhaust gas up or downstream of turbine (turbocharger) ; require back pressure restriction and/or intake throttle to flow exhaust gas to intake system **(fuel economy penalty)**
- **Cool exhaust gas** before dumping into intake system; **additional engine system cooling requirement)**; **non-ram air scenarios will have additional fuel economy penalty!**
- Temperature control of EGR crucial in order to avoid formation of **sulfuric acid that expedites engine wear and impacts engine reliability (and durability)**
- This concept introduces particulates and sulfuric acid into cylinder ; **requires more frequent oil change; certification of new lubricants (not on QPL)**

One particular precision air and fuel management strategy

- A non-EGR solution
- Limited variable intake valve timing ; **extra valve train sophistication**
  - **'cooler' combustion temperatures**
- **Two stages of turbocharging (single stage for smaller displacement engines)**
- **Additional charge air cooling necessary** ; increase in required engine system heat rejection – **not as significant impact as cooled EGR**
- **Passive oxidation catalyst** and **diesel particulate filter (DPF)** in some applications along with **low pressure EGR** on certain 2007 MY applications



2007 Emission Issues : Aftertreatment Devices (example)

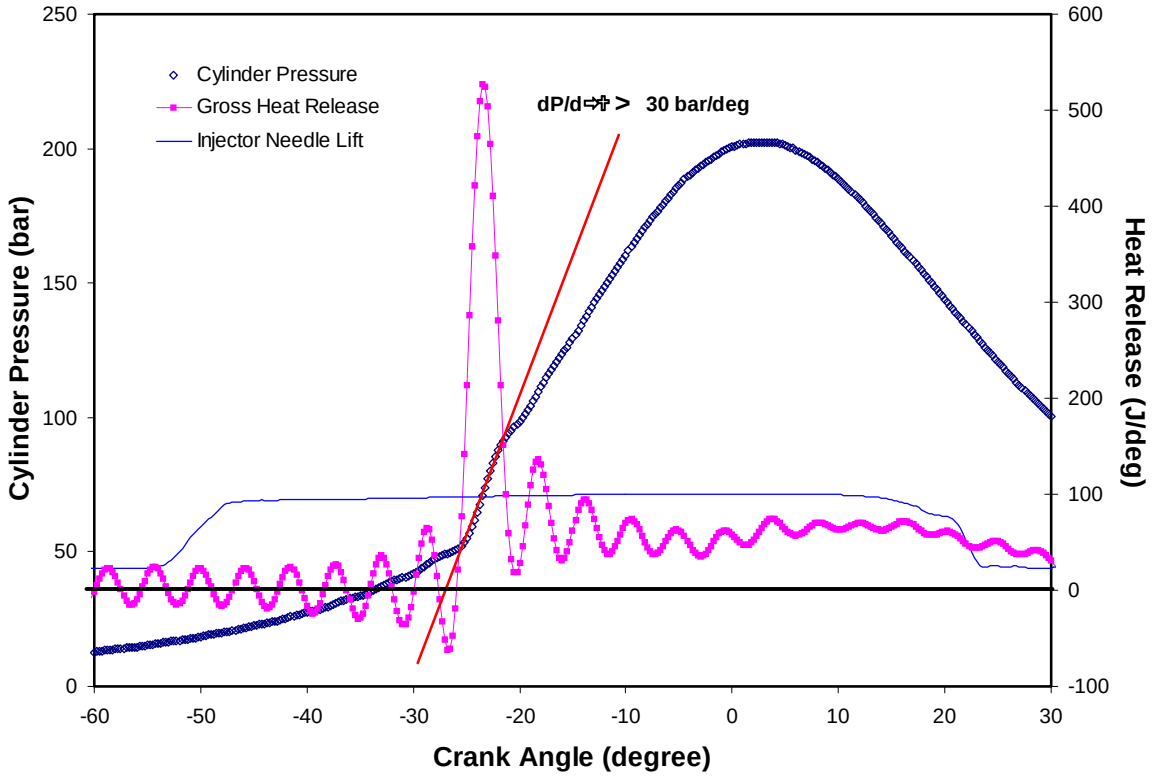


1998 engine

- **PM filters / NOx reduction devices**
  - Catalyzed filters (DOC + CDPF) - 2007
  - NOx trap (adsorber) vs. Urea SCR (selective catalytic reductant) – 2010
  - Additional space claim , **conservatively 2.5 - 5 times the engine displacement**
- **NOx trap requires 15 ppm fuel sulfur level**
- Likely to include high levels of EGR in additional to NOx aftertreatment device
  - higher heat rejection (~ 50% increase vs. MY1998)
- Push toward new oil formulation to extend CDPF lifetime and improve oil drain interval
- Urea SCR requires on-vehicle, urea storage tank and 'safeties' to ensure vehicle operator compliance; urea quality sensor, cold weather freeze avoidance, empty tank precautions

New Combustion Regimes

- High Pressure Rise Strategies: HCCI, PCCI, etc.
  - fuel ignition quality and evaporation characteristics important
  - JP-8 ‘loose’ property specifications, i.e. CN dependent on supply source



Fuels and Lubricants Discussion

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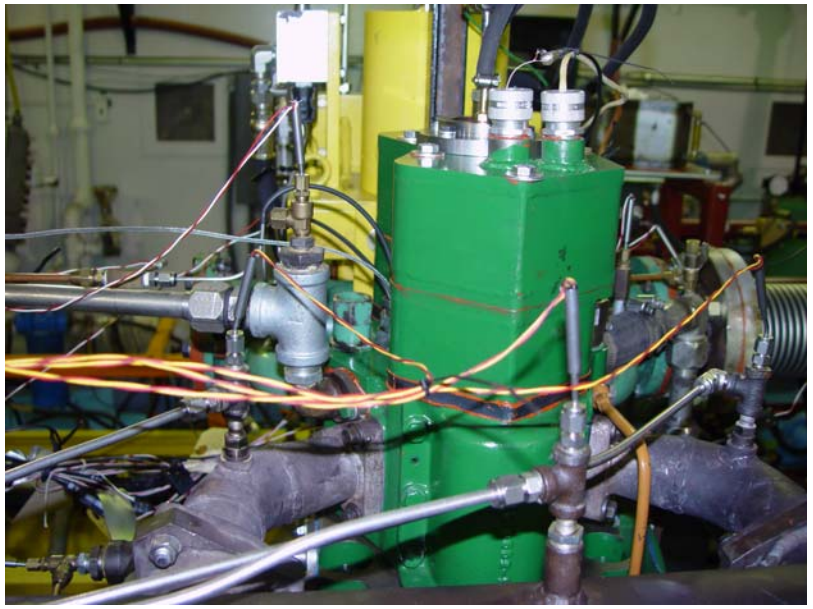
JP-8 Property Specifications

- **Sulfur content: max. 3000 ppm**
- Aromatics: max. 25%
- Specific gravity: 0.775 – 0.84
- Evaporation Characteristics:
  - 10% recovery: max. 205 C (186 C)
  - End point: max. 300 C (330 C)
- Net Heating Value: min. 42.8 MJ/kg
- **Cetane Index: none**



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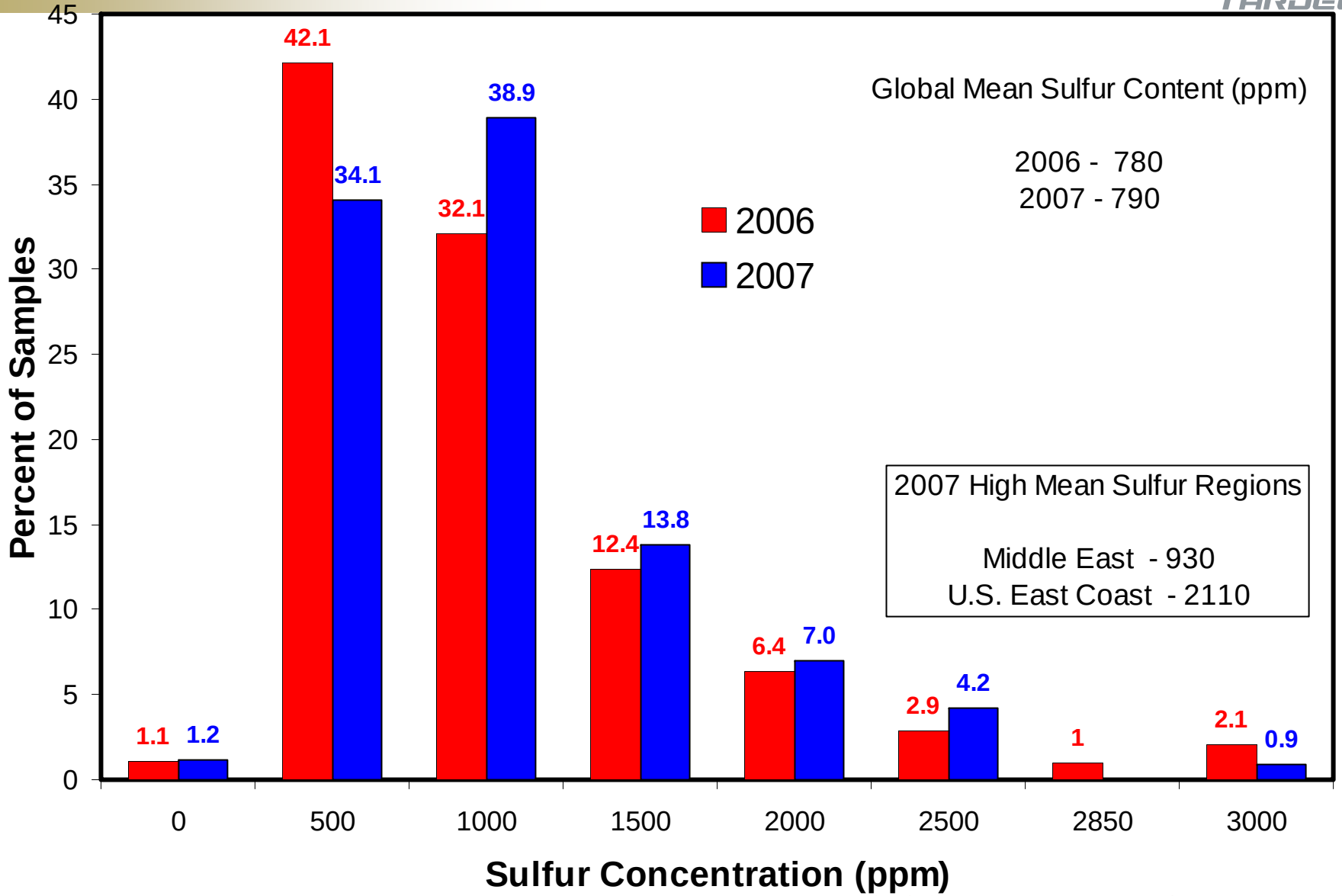
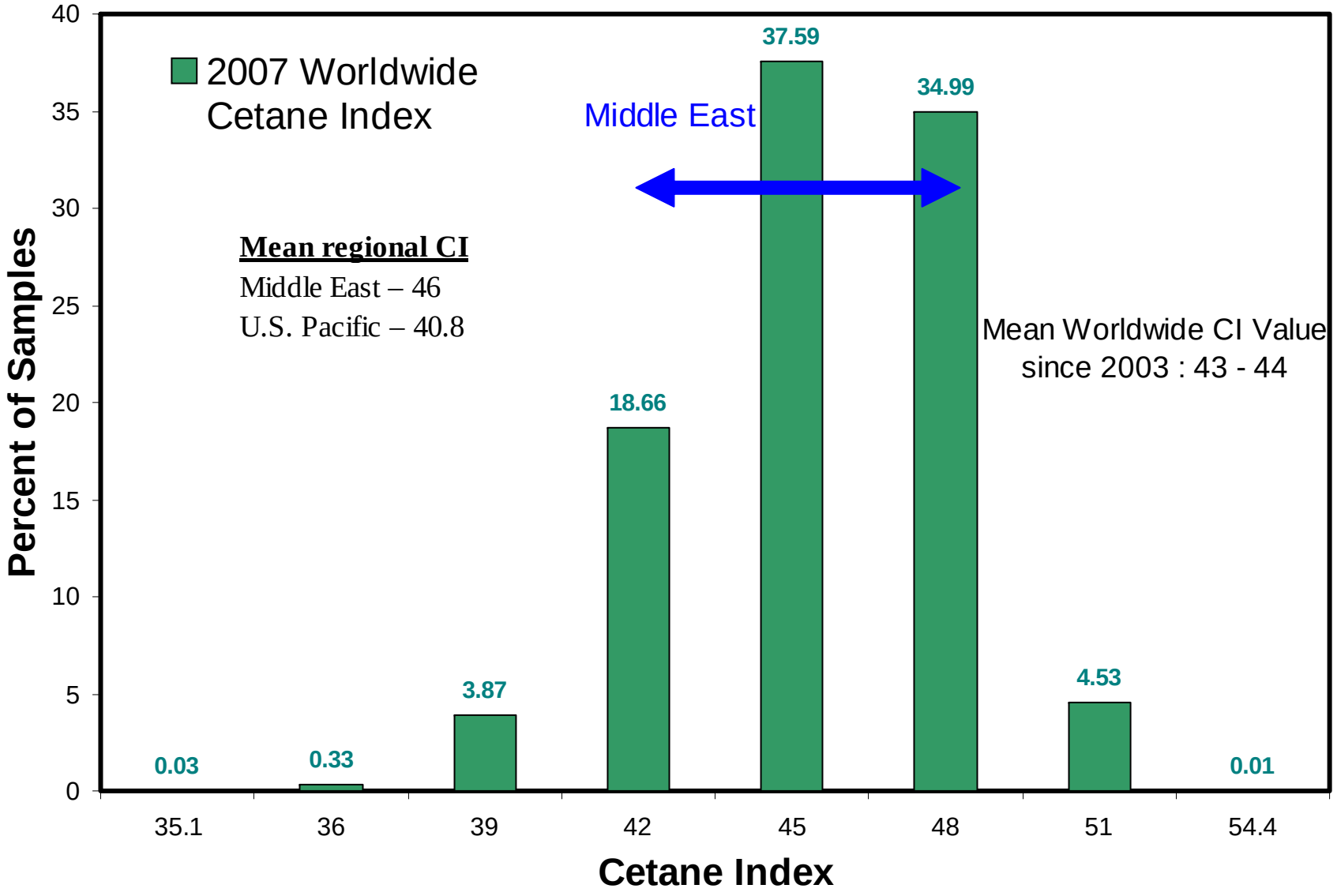
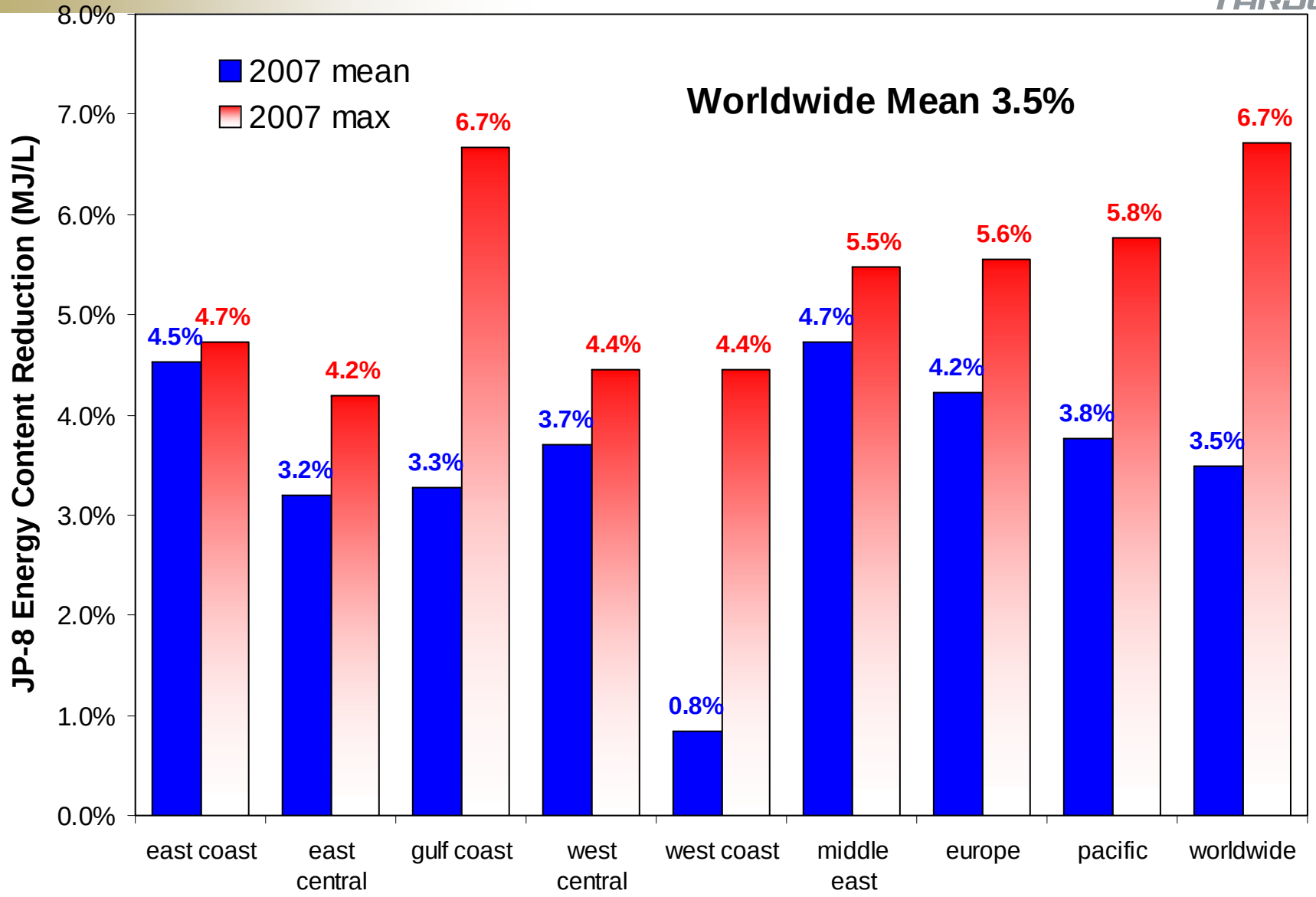
JP-8 Fuel Sulfur Content Example: Worldwide



JP-8 Cetane Index Worldwide Trend in 2007



JP-8 Energy Volumetric Energy Content



Impact of Emission Standards on Military Heavy-Duty Diesel Engine/Transmission Oils (E/TO) – Performance concerns

- US Market Drivers for lubricants
  - Ultra-low-sulfur fuels (ULSF)
  - Compatibility with pollution prevention devices (toward low ash, phosphorus, and sulfur concentrations)

- Some additive technologies proven to work well with higher sulfur fuels will not be allowed in the future
  - Additives with phosphorus and ZDDP (zinc dialkyl dithiophosphate)
  - Due to 'poisoning' of pollution devices

- Military exposure to high sulfur fuels raises concerns regarding engine protection with lubricant technology developed around ULSF
  - Logistic and Maintainability concerns
  - Compability of new oils with 'older' systems

- Unknown impact of future engine oils on transmission performance
  - No commercial interest.

Current Army Ground Vehicle Engine Philosophy and Conclusion

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Solution Pathways – Long Term to 2007/2010 Heavy-Duty On-Road Emission Standards

- All engine systems have or are heading toward some type of aftertreatment system with advanced combustion strategies and closed loop control

  - NOx trap, catalyzed filters (CDPF/DOC), urea or fuel based SCR
  - HCCI, PCCI, and other more 'homogeneous combustion modes'
  - LTC : low temperature combustion for light loads, possible regeneration strategy
  - **Heavy use of cooled EGR (>50% heat rejection increase vs. MY 1998)**
    - possible low pressure cooled EGR in some cases
  - Exhaust sensors for temperature(s), pressure(s), NOx concentration, O_2 concentration, ammonia, urea
    - Closed loop control package for monitoring and regenerating aftertreatment devices
  - **Commercial diesel fuel properties may require tighter combustion related property specifications for advanced combustion system operating modes**

Solution Pathways – Long Term to 2007/2010 Heavy-Duty On-Road Emission Standards

- Engine systems **must be modified** to meet military requirements
  - Use of NSE for MY 2004 & 2007+ and Tier IV engine systems
  - Removal of EGR system
  - Removal of aftertreatment devices
  - Recalibration for best vehicle performance (Mobility), optimal fuel consumption, and lowest heat rejection
  - Ensure high sulfur fuel tolerant and oil compatible components
  - **Unknown on how to handle fuel lubricity filter technology**

Conclusion

- The Army can not buy 2007 or Tier IV (> 75 bhp) compliant COTS engines and directly integrate into current and new heavy-duty vehicles.

New FY08 Science And Technology Programs

- High Pressure Common Rail Pump Lubricity Assessment Programs
  - Alternative Fuel Technology, LLC (Phase I SBIR)
  - Analytical Engineering Inc. (Phase I SBIR)
  - Cummins Inc.
- Engine Performance Assessment Programs
  - Mack Truck, Inc. (MP8 13L)
  - Cummins Inc. (ISL 8.9L)

THANKS!

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